Physicochemical and Functional Properties of Wheat (Triticum aestivum) and Selected Local Flours in the Philippines

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Exploring locally available wheat alternatives will be advantageous to the domestic flour and baking industry and to the Filipino farmers. This will also offer value-added products to the growing gluten-free market. The physicochemical and functional properties of different flours (non-glutinous and glutinous rice, sweet potato, mung bean, banana, and sago) were determined and compared with all-purpose wheat flour. The bread quality parameters of these flours were correlated with flour properties. The commercially available flours (wheat, rice, sweet potato) were significantly whiter than the mung bean, banana, and sago flours. In terms of proximate composition, mung bean flour had the highest protein (22.57%), fiber (2.19%), and ash (4.72%) contents among the flours. Sweet potato flour, on the other hand, had the highest total carbohydrates (85.22%), starch (81.50%), and amylose (26.30%) contents. It was the most viscous but was unstable upon heating (i.e., highest peak and breakdown viscosities). Banana flour had the highest water absorption capacity and the second highest swelling power at 85°C next to sago flour. The absence of gluten in the non-wheat flours led to firmer and denser bread. Bread from inherently pigmented flours had a significantly darker crumb, but only mung bean flour produced a significantly darker crust than the control (100% wheat). Correlation analysis revealed that using flours with relatively lower fiber and amylose contents, smaller particle size, and lower breakdown viscosity – but higher water absorption capacity – lowers the chances of producing firm and dense bread.

Key words: bread quality, functional properties, gluten-free flours, physicochemical properties, wheat flour

INTRODUCTION

Wheat-based products, specifically bread, play a dominant role in the Philippine diet. In 2015-2016, the country’s per capita consumption of pandesal and sliced bread was 211 pieces and 5 packs per year, respectively (PSA 2017). Moreover, though rice is still the staple food, bread is its leading substitute commodity. Wheat flour is commonly used in baked products because of its gluten proteins that provide the desired texture and structure. However, there is a need to identify and characterize wheat alternatives because of health and economic reasons. There is a rising consumer interest in wheat-free products primarily by those who suffer from celiac disease and gluten intolerance. Refined wheat products have also been associated with unwanted weight gain, diabetes, poor digestive health and cardiovascular diseases because of its high glycemic index (Asia Pacific Food Industry 2014). From an economic perspective, the Philippines’ dependence on wheat importation and the

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increasing price of wheat in the global market negatively impact the consumer’s buying capacity. Thus, having alternative, more sustainable sources and accessible flours will contribute to addressing these issues.

Potential wheat alternatives are flours from rice, sweet potato, sago, mung bean, and banana. These flours are locally available, gluten-free, and most have nutritive advantages over wheat flour. Rice flour is a common ingredient in gluten-free products because it is hypoallergenic, easily digested, white, and bland (Kadan et al. 2001); it will not interfere with the flavor profile of the product. Sweet potato can be used to produce nutritious flour because of its high vitamin and mineral content that include pro-Vitamin A (beta-carotene), Vitamin C, magnesium, and potassium, among others (Adelaye & Akingbala 2016). Sago (Metroxylon sagu) is mostly processed for starch, but its flour is reported to have relatively high fiber content and low digestibility (Karim et al. 2008; Castro 2009). Mung bean is a common and affordable vegetable protein source in the Philippines and its flour has functional properties that will make it useful in baked products and confections (Del Rosario & Flores 1981). Lastly, unripe banana fruits – including off-grade ones based on size or peel appearance – can be made into flours. Banana flour has high fiber and resistant starch contents (Da Mota et al. 2000), which translates to a low glycemic index.

There is limited information on the processing or functional properties of these flours, particularly those cultivars produced in the Philippines. Even though they have higher nutritive value, they are gluten-free and may cause processing-related difficulties since gluten contributes to favorable appearance and crumb structure of baked products. Hence, comparing their physicochemical and functional properties with wheat flour is essential.

In line with this, this study was conducted to analyze the physicochemical and functional properties of flours from wheat, glutinous and non-glutinous rice, sago, sweet potato, mung bean, and banana; determine the effect of the flours on bread quality parameters; and correlate flour and bread properties.

The output of this study may be used as a guide by food processors in selecting flours depending on the desired function or end product quality. This may also result in further diversification of flour-based products specifically the emergence of gluten-free foodstuff in the Philippine market. In the long run, this may gradually decrease the country’s dependence on wheat flour imports, thus increasing the utilization of local crops which will be beneficial to the farmers.

**MATERIALS AND METHODS**

**Source of Flours**
Wheat (all-purpose), sweet potato, and glutinous and non-glutinous rice flours were purchased from the supermarket. Banana flour from unripe Cardava variety was obtained from Kapalong, Davao del Norte, whereas dry-milled sago flour was obtained from the University of the Philippines Mindanao. Mung bean flour was processed using the method of Mauleon (2015). The non-wheat flours represent different sources, namely: cereal grains (glutinous and non-glutinous rice flour), root crop (sweet potato flour), legume (mung bean flour), fruit (banana flour), and pith of palm tree (sago flour).

**Physicochemical Properties Determination**

**Particle Size Distribution.** US sieve sizes of 100, 140, and 200 mesh – with 149 μm, 105 μm, and 74 μm openings, respectively – were used. Flour samples (50 g) were weighed and put on the top sieve and covered. The nest of sieves was placed on a shaker at high speed for 30 min and the remaining material on each sieve was then weighed. The mass fraction of flour retained on each sieve was calculated in relation to the initial mass of the sample. This test was done in triplicates.

**Color.** The color of the flour samples was determined using a Precision Colorimeter (CLRM 110, MRC, Israel). CIE L*, a*, and b* values were collected. L* relates to brightness and ranges from 0 to 100, which corresponds to black to white. The a* value ranges from green (negative) to red (positive), and the b* value ranges from blue (negative) to yellow (positive). A white standard was used to calibrate the instrument. Three measurements were taken per flour sample.

**Proximate Composition.** Moisture, crude ash, crude fat, crude fiber, crude protein, and total carbohydrates contents were determined following the Official Methods of Analysis of the AOAC (1990). Three replicates per flour were analyzed.

**Total Starch Content.** The total starch content was analyzed using a Megazyme Total Starch Assay Kit® (Megazyme International Ireland, Bray, Co. Wicklow, Ireland). This test uses the amyloglucosidase/alpha-amylase method based on AOAC Official Method 996.11 and AACC Method 76.13.01.

**Apparent Amylose Content.** Apparent amylose content determination was done through a colorimetric assay based on AACC Method 61-03 (AACC International 2000).

**Analysis of Functional Properties**

**Water and Oil Absorption Capacity.** Beuchat’s (1977) methods, with modifications, were employed in the determination of the water and oil absorption capacity.
of the flour samples. One gram (1 g) of flour was mixed with 10 mL of distilled water or canola oil in a centrifuge tube and was allowed to stand at room temperature for 1 h. This was followed by centrifugation for 30 min at 3000 rpm. The volume of the decanted supernatant fluid was measured and the volume of water or oil retained was determined. Water and oil absorption capacities were calculated as mL of water or oil absorbed per gram of flour.

**Swelling Power and Solubility.** The swelling power and solubility of flours were determined using the method of Eriksson and co-authors (2014).

**Pasting Property.** The pasting profile of 12% slurry was taken with a Rapid Visco Analyzer (RVA Model 4, Newport Scientific Pty. Ltd, Sydney, Australia). The temperature profile that was used started at 50°C and increased linearly to 95°C, followed by a holding step at 95°C, then cooling to 50°C, for a total run time of 12.5 min. Peak, trough, final, breakdown (difference of peak and trough), and setback (difference of final and trough) viscosities, pasting temperature, and peak time were determined.

**Gel Formation Ability.** The method of Mejia-Agüero and colleagues (2012), with modifications, was used to observe gel formation ability of the flours. Flours were mixed with distilled water (8% w/v) in a 15 mL centrifuge tube. The samples were then placed in a 95°C water bath for 30 min with constant shaking. After cooling to room temperature, it was centrifuged at 3000 rpm for 20 min and the supernatant was discarded. Gel formation ability was indicated by the presence of a soft gel.

**Production of Bread.** AACC Method 10-10.03 or the Optimized Straight-Dough Bread-Making Method was employed in the production of loaf bread (AACC International 2000). The samples consisted of bread with 100% wheat flour (control) and 50:50 wheat: non-wheat flour blends. Three hundred grams (300 g) of flour, 5.4 g instant dry yeast, 18 g refined sugar, and 4.4 g salt were mixed for 1 min at speed 2 using a KitchenAid® stand mixer (Model 5K5SS, KitchenAid, Belgium). After which, 9 g of shortening was added and then it was mixed further for 3 min at the same speed. The paddle was replaced with a hook, and about 170 g of water was added. It was mixed for 1 min at speed 1 and for 7 min at speed 4. The dough was proofed for 52 min at 30°C and 89% relative humidity (RH), punched, and then further proofed for 25 min. It was then placed in pans and proofed for another 13 min. Baking was carried out at 200°C for 24 min. After cooling, the bread samples were wrapped in aluminum foil, kept in polyethylene bags, and stored at ambient conditions (26°C and 67% RH). These were evaluated for color, firmness, specific volume, and density after 24 h.

**Analysis of Bread Characteristics**

**Bread Firmness.** AACC Method 74-09 (AACC International 2000) was followed to determine bread firmness using a Universal Testing Machine (Shimadzu, Model EZ-S, Kyoto, Japan). Each loaf was cut with a serrated knife into 25 mm thick cubes, being careful not to damage the crumb structure, and the samples were kept in a covered plastic container to avoid moisture loss. Each sample was then evaluated by placing it in the center of the platform under the compression jig. The test was set to a speed of 100 mm/min and to a 40% compression.

**Bread Specific Volume, Density, and Color.** Bread volume was determined using a modified rapeseed displacement method (Sahin & Sumnu 2006). Sesame seeds were used in place of rapeseeds. The specific volume and density of the bread samples were determined by getting the ratio of bread volume to bread weight and bread weight to bread volume, respectively. The bread samples’ crumb and crust color parameters were determined using the same method for the flour samples.

**Statistical Analysis**

One-way Analysis of Variance (ANOVA) at 5% probability was used to determine whether the difference among the flour samples was significant. A Randomized Complete Block Design (RCBD) was selected for the analysis of the bread qualities, with the two baking batches as blocks. The Tukey’s HSD at 5% probability level was used to find means that were significantly different from each other. Moreover, the relationships between the bread quality parameters and flour properties – and between functional and physicochemical properties of flours – were examined using Pearson’s correlation coefficient, r:

**IBM® SPSS® Statistics 24 (2016) was used in running all these statistical analyses.**

**RESULTS AND DISCUSSION**

**Physicochemical Properties of the Flour Samples**

**Particle Size Distribution.** Figure 1 shows the mass fraction retained in each sieve or particle size distribution of the flour samples. Sweet potato flour had the highest mass fraction retained in the mesh 100 sieve (72.50%), which means that it had the largest particle size since only a small percentage of it passed through the opening of 149 µm. The bulk of the wheat (52.59%), glutinous (65.38%) and non-glutinous (58.29%) rice flours were retained in the mesh 140 sieve, which means mostly a particle size between 105 to 149 µm. Sago flour had the highest mass fraction that passed through all the sieves and was collected in the pan. This implies that sago flour was the
finest among the flours since most of it went through the 74 µm opening.

Particle size is dependent on the cell or granule structure, type, and degree of processing, and chemical composition (Sahin & Sumnu 2006). This data may be used to predict enzymatic digestion of starch as well as dough hydration and bread quality. De La Hera and co-workers (2014) reported that rice flour with smaller particle size formed weak dough structure due to its inability to retain the gas released during fermentation. On the other hand, small particle size is suitable for food products that require a smooth texture (Freitas et al. 2004).

**Color Profile.** The flours significantly varied in color (Table 1). The $L^*$ values of the flours ranged from 59.98 to 80.72. Non-glutinous rice flour had the highest $L^*$ value, which means that it was the whitest among the flours. However, this was not significantly different from the other commercially-available, white flours (wheat, glutinous rice, and sweet potato). Sago flour, on the other hand, had the lowest $L^*$ value, which means that it was the darkest flour. It was not significantly different from mung bean and banana flours.

The dark color of sago flour can be attributed to its polyphenol compounds like catechin and epicatechin, which are oxidized during flour production (Anthonysamy et al. 2004; Karim et al. 2008). The rapid browning of unripe banana during peeling and slicing is also due to enzymatic oxidation by polyphenol oxidase and peroxidase upon tissue disruption and exposure to oxygen (Cano et al. 1997). In the case of mung bean flour, the

**Table 1.** Color profile of the flour samples.

<table>
<thead>
<tr>
<th>Flours</th>
<th>Color parameters</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$L^*$</td>
<td>$a^*$</td>
<td>$b^*$</td>
</tr>
<tr>
<td>Wheat</td>
<td>71.98 $^{bcd}$</td>
<td>1.78 $^a$</td>
<td>7.40 $^b$</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>73.92 $^{bcd}$</td>
<td>1.95 $^a$</td>
<td>7.50 $^b$</td>
</tr>
<tr>
<td>Non-glutinous rice</td>
<td>80.72 $^{d}$</td>
<td>0.70 $^a$</td>
<td>4.26 $^a$</td>
</tr>
<tr>
<td>Glutinous rice</td>
<td>74.29 $^{cd}$</td>
<td>0.68 $^a$</td>
<td>6.20 $^{ab}$</td>
</tr>
<tr>
<td>Mung bean</td>
<td>64.24 $^{abc}$</td>
<td>6.92 $^c$</td>
<td>19.42 $^d$</td>
</tr>
<tr>
<td>Banana</td>
<td>63.37 $^{ab}$</td>
<td>4.73 $^b$</td>
<td>14.15 $^c$</td>
</tr>
<tr>
<td>Sago</td>
<td>59.98 $^a$</td>
<td>8.22 $^c$</td>
<td>19.81 $^d$</td>
</tr>
</tbody>
</table>

Means in columns with different superscripts are significantly different at $p<0.05$. 

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**Figure 1.** Particle size distribution of wheat (all-purpose) and non-wheat flour samples.
pigmentation may be partly due to the roasting process and the presence of mung bean hulls.

High a* values indicate reddish color. Sago had the highest a* value, which was significantly different from that of the other flours except for mung bean flour. The "white flours" had similar low a* values, which means that they had less red components than the other flours. High b* values represent yellowish color. Sago and mung bean flours had the highest b* values that were significantly different from the other flours. On the other hand, non-glutinous rice flour had the lowest b* value and this was significantly different from the rest of the flours except for glutinous rice flour. Overall, non-glutinous rice flour is the brightest due to its high L*, low a*, and low b* values.

Color is an important quality attribute in foods because it affects consumer acceptability. Specifically, flour color is important to note because it affects crumb color of a finished product (Sahin & Sumnu 2006). For wheat flour, color testing is done to evaluate its whiteness, which determines the extent of oxidation of carotenoid pigments by bleaching agents (Guine & Correia 2014).

**Proximate Composition.** The proximate composition of the flour samples is shown in Table 2. Mung bean and non-glutinous rice flours had the lowest (7.47%) and highest (15.63%) moisture contents, respectively, and both were significantly different from the other flours. When the moisture content of flours is more than 14%, mold growth, flavor changes, enzyme activity, and insect infestation are likely to occur (Figoni 2011). Hence, all the tested flours, except for non-glutinous rice flour, can be considered shelf stable.

Wheat, sweet potato, non-glutinous and glutinous rice, and sago flours had no significant difference in crude ash content, which ranged from 0.16% to 1.34%. On the other hand, the crude ash content of mung bean (4.72%) and banana (3.17%) flours was significantly higher than the aforementioned flours. These values are relatively close to reports of 3.42% in mung bean flour (Kavitha & Parimalavalli 2014) and 2.6-3.5% in banana flour (Da Mota et al. 2000). The high crude ash of mung bean and banana flours can be attributed to relatively high mineral content. Mung bean is rich in iron, zinc, calcium, magnesium, phosphorus, and potassium (Tapash et al. 2011). Similarly, banana is rich in potassium (Bezemek 2015).

The crude protein content of mung bean flour (22.57%) was significantly higher compared to that of the other flours since legumes are naturally rich in protein, but they lack gluten proteins. This value is comparable to the 21.90% crude protein content reported by Kavitha and Parimalavalli (2014). Mung bean flour was followed by wheat flour, but the latter has gluten proteins. Sago and sweet potato flours had the lowest protein contents.

Flours in general have relatively low fat content. Among the samples, sweet potato had the highest crude fat content (1.65%) while banana flour had the lowest (0.17%). Wheat flour’s crude fat content had no significant difference from the other flours.

Mung bean flour had the highest crude fiber content (2.19%), which was significantly greater than that of the other flours. This value is lower than the 3.80% value of Kavitha and Parimalavalli (2014). The crude fiber content of the cereal grains (wheat and rice), sweet potato, and sago flours was similar.

Except for mung bean flour that had the lowest total carbohydrate content, all the other flours were not significantly different in values, which ranged from 78.52% to 85.22%. Flours from any source are typically rich in carbohydrates.

Proximate composition approximates nutrients present in the flour and can be used to estimate the nutritional quality of food products for which they will be used. Moreover, some components correlate with functional properties. Protein content, for example, influences the baking properties of flours. Crude fat content can be used to estimate the nutritional value of the flour.

Table 2. Proximate composition, total starch, and amylose content of the test flours.

<table>
<thead>
<tr>
<th>Flours</th>
<th>Moisture (%)</th>
<th>Crude ash (%)</th>
<th>Crude protein (%)</th>
<th>Crude fat (%)</th>
<th>Crude fiber (%)</th>
<th>Carbohydrate (%)</th>
<th>Total starch (%)</th>
<th>Apparent amylose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>12.74 ^d</td>
<td>0.42 ^a</td>
<td>13.60 ^d</td>
<td>1.18 ^abcd</td>
<td>0.13 ^ab</td>
<td>78.80 ^b</td>
<td>72.70 ^b</td>
<td>21.40 ^c</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>12.53 ^cd</td>
<td>0.16 ^a</td>
<td>0.70 ^ab</td>
<td>1.65 ^c</td>
<td>0.17 ^ab</td>
<td>85.22 ^b</td>
<td>81.50 ^d</td>
<td>26.30 ^d</td>
</tr>
<tr>
<td>Non-glutinous rice</td>
<td>15.63 ^f</td>
<td>0.43 ^a</td>
<td>8.84 ^e</td>
<td>0.23 ^a</td>
<td>0.05 ^a</td>
<td>78.52 ^b</td>
<td>80.68 ^cd</td>
<td>24.30 ^cd</td>
</tr>
<tr>
<td>Glutinous rice</td>
<td>12.29 ^c</td>
<td>0.36 ^a</td>
<td>6.72 ^e</td>
<td>0.46 ^ab</td>
<td>0.03 ^a</td>
<td>80.86 ^b</td>
<td>80.46 ^cd</td>
<td>1.25 ^s</td>
</tr>
<tr>
<td>Mung bean</td>
<td>7.47 ^a</td>
<td>4.72 ^b</td>
<td>22.57 ^e</td>
<td>1.42 ^bc</td>
<td>2.19 ^c</td>
<td>71.17 ^s</td>
<td>43.17 ^a</td>
<td>13.20 ^b</td>
</tr>
<tr>
<td>Banana</td>
<td>9.02 ^b</td>
<td>3.17 ^b</td>
<td>3.33 ^b</td>
<td>0.17 ^a</td>
<td>0.91 ^b</td>
<td>83.60 ^b</td>
<td>75.40 ^bc</td>
<td>24.85 ^cd</td>
</tr>
<tr>
<td>Sago</td>
<td>13.32 ^c</td>
<td>1.34 ^a</td>
<td>0.19 ^a</td>
<td>0.20 ^a</td>
<td>0.61 ^ab</td>
<td>83.89 ^b</td>
<td>76.55 ^bcd</td>
<td>24.90 ^cd</td>
</tr>
</tbody>
</table>

Means in columns with different superscripts are significantly different at p<0.05.
to predict the swelling behavior of starch and baking quality of flours; high flour lipid content significantly decreases bread volume (Guine & Correia 2014). In addition, moisture and crude fat content are determinants of storage stability of the flours; high amounts lead to microbial growth and rancidity, respectively.

**Total Starch Content.** Mung bean flour had the lowest starch content (43.17%) and this was significantly different from the rest of the flours (Table 2). Like total carbohydrates, this is expected to be low since a large portion of legume flours is protein. Sweet potato flour had the highest total starch content (81.50%), which was only significantly greater than that of wheat, banana, and mung bean flours. High starch content in flour generally leads to high swelling power, solubility, and water-binding capacity (Eriksson et al. 2014). Flours with high starch content will be more suited for applications where the functionality of starch is crucial.

**Apparent Amylose Content.** Table 2 also shows the amylose content of the flours. Glutinous rice flour had the lowest amylose content with only 1.25% and this was significantly lower than the rest of the flours. This is expected since glutinous or waxy flours generally have negligible to no amylose, only amylopectin. Sweet potato flour, on the other hand, had the highest amylose content (26.30%), which was also significantly different from the other flours. The rest of the flours had intermediate amylose content (i.e., within the 20% to 25% range), except for the mung bean flour that had low amylose content (13.20%). The determination of the ratio of amylose to amylopectin content is important because this influences the end-use properties of starches as a whole. High-amylose starches are not suitable for frozen products, such as creams or fillings because they tend to weep or release water over time (Figoni 2011). Hence, it can be said that sweet potato flour cannot be used for these applications. Conversely, high-amylopectin starches are less likely to weep during storage and are very thick, whether cold or hot. This is the reason why they are used as the main ingredient in famous Filipino snacks such as *suman* and *binignit*.

**Functional Properties of the Flour Samples**

**Water and Oil Absorption Capacity.** The water absorption capacities (WAC) of the flours ranged from 0.89 to 1.82 mL of water/g of flour (Table 3). Banana flour had the highest WAC (1.82 mL/g) while sweet potato flour had the lowest (0.89 mL/g). The latter may be partly due to the large particle size of sweet potato flour, which translates to a smaller surface area that is exposed to water (Mariotti et al. 2009). Moreover, a significant negative relationship was found between WAC and crude fat content ($r=-0.508, p<0.05$). The hydrophobic property of fats reduces the ability of the flour to absorb water. On the other hand, there was no significant difference in the oil absorption capacity values among the flours, which ranged from 0.88 to 1.27 mL of oil/g of flour.

The determination of WAC is important because it affects bread baking. High water absorption is desirable in bread baking because the rate of staling is slowed down due to the added moisture (Figoni 2011). On the other hand, oil absorption capacity data can be used to predict the palatability of a flour-based product since oil increases mouthfeel and retains flavor (Aremu et al. 2007).

**Swelling Power and Solubility.** The swelling power of the flours at 85°C varied significantly (Table 3). Glutinous rice flour had the lowest swelling power (6.83 g/g) while *sago* flour had the highest (13.26 g/g). Adeyeye and Akingbala (2016) reported that cereal flours have higher swelling power than tuber flours. However, in this study, only wheat flour had a significantly higher swelling power than sweet potato and non-glutinous and glutinous rice flours. Swelling power is mainly influenced by amylose content, especially with the presence of other flour components. According to Shimelis and co-authors (2006), amylose and lipids form insoluble complexes that decrease swelling power. Similarly, proteins lower the swelling power by forming a stiff matrix when they are being embedded in the starch granules, thus limiting the access of water (Aprianita et al. 2014). From these, it is commonly reported that swelling power is inversely proportional to protein, fat, and amylose content (Sasaki & Matsuki 1998; Phattanakulkkaewmorie et al. 2011). However, these relationships were not observed in this study. Swelling power had a highly significant, positive correlation with amylose content ($r=+0.691, p<0.01$), but was not significantly correlated with either crude fat or protein content. Furthermore, swelling power had a significant, positive relationship with mass fraction retained in the pan ($r=+0.607, p<0.01$), and a significant

<table>
<thead>
<tr>
<th>Flour</th>
<th>WAC* (mL/g)</th>
<th>OAC* (mL/g)</th>
<th>Swelling power at 85°C (g/g)</th>
<th>Solubility at 85°C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1.31 a</td>
<td>0.88 a</td>
<td>11.01 cd</td>
<td>10.10 bc</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>0.89 c</td>
<td>1.00 b</td>
<td>9.48 b</td>
<td>39.70 d</td>
</tr>
<tr>
<td>Non-glutinous rice</td>
<td>1.37 b</td>
<td>1.27 a</td>
<td>9.25 b</td>
<td>2.53 c</td>
</tr>
<tr>
<td>Glutinous rice</td>
<td>1.56 bc</td>
<td>1.22 a</td>
<td>6.83 a</td>
<td>9.40 ab</td>
</tr>
<tr>
<td>Mung bean</td>
<td>1.45 b</td>
<td>1.10 a</td>
<td>9.90 bc</td>
<td>16.92 c</td>
</tr>
<tr>
<td>Banana</td>
<td>1.82 c</td>
<td>1.03 a</td>
<td>11.69 d</td>
<td>8.03 ab</td>
</tr>
<tr>
<td>Sago</td>
<td>1.49 b</td>
<td>1.21 a</td>
<td>13.26 c</td>
<td>11.54 bc</td>
</tr>
</tbody>
</table>

Means in columns with different superscripts are significantly different at $p<0.05$; *WAC – water absorption capacity, OAC – oil absorption capacity.*
negative relationship with mass fraction retained in mesh 140 \((r=-0.580, p<0.01)\). This suggests that smaller flour particles tend to undergo greater starch swelling.

The solubility values of the flours were greatly varied, ranging from 2.53\% (non-glutinous rice flour) to 39.70\% (sweet potato flour) (Table 3). A highly significant, positive correlation was found between solubility and mass fraction retained in mesh 100 \((r=+0.770, p<0.01)\). This means that the flour samples with bigger flour particle size tended to have greater leaching of starch. Other factors that may affect solubility include the structure of the starch granules and difference in the inter-associative forces within the amorphous and crystalline structures (Kusumayanti et al. 2015). Mung bean flour had the second highest solubility despite having the lowest total starch content, but this was not significantly different from the wheat and sago flours. The observed dissolved components from mung bean flour may be its soluble nitrogenous compounds (Del Rosario & Flores 1981).

**Pasting Property.** Figure 2 shows the paste viscosity profiles of wheat and non-wheat flours. All the gluten-free flours had a pasting temperature greater than that of wheat flour (66.55°C). This means that gluten-free flours may need more energy and a longer cooking time to form a paste and are more resistant towards swelling (Teng et al. 2013). In addition, higher protein flours in general needed more time to reach its peak viscosity \((r=+0.742, p<0.01)\). On the other hand, a higher starch content shortened the peak time \((r=-0.589, p<0.01)\).

Sweet potato (5287.5 cP), glutinous rice (4007 cP), and sago (2870 cP) flours had the highest peak viscosities. All the flours varied significantly in their peak viscosities, except for the cereal flours – wheat and non-glutinous rice (2122 cP and 2091 cP, respectively). This confirms earlier findings that cereal starches have lower peak viscosities than tuber starches (Eriksson et al. 2014). Glutinous rice flour had the least amylose content, thus starch granules swelled rapidly and greatly. In the case of sweet potato and sago flours, their high peak viscosities can be attributed to their low protein contents. It was found that peak viscosity had a strong negative relationship with crude protein \((r=-0.813, p<0.01)\). On the other hand, mung bean flour had the lowest peak viscosity. The roasting process during flour production may have gelatinized and retrograded some starch granules. Its high fiber content might have also restricted the swelling of starch granules (Julianti et al. 2015). This can be further supported by the negative correlation between peak viscosity and crude fiber content \((r=-0.618, p<0.01)\).

Breakdown viscosity measures the ease with which the swollen granules can be disintegrated, thus approximates stability during thermal processing (Kaur & Singh 2005; Eriksson et al. 2014). The highest breakdown viscosity was recorded in sweet potato flour (3056.5 cP), followed by glutinous rice (1861.5 cP) and sago (1770 cP) flours. Mung bean flour had a relatively flat curve and so no breakdown value was recorded. Debet and Gidley (2006) reported that starches that swell rapidly on heating tend to

![Figure 2. Viscosity profile of wheat (all-purpose) and non-wheat flours.](image-url)
be more shear sensitive, and this is reflected in the three flours with the highest breakdown viscosity. Conversely, a flat curve indicates that the starch granules resist expansion or breaking during the hydrothermal treatment (Ascheri et al. 2012). The slow viscosity development of flours with flatter curves may be due to the interaction between lipid and starch granules, which in turn prevents complete hydration (Thomas & Atwell 1999). Moreover, a protein-starch interaction may have also affected breakdown viscosity. In this study, a negative correlation was found between crude protein and breakdown viscosity ($r=-0.636, p<0.01$).

The final viscosity is the viscosity of the cooled gel, while setback approximates the retrogradation tendency of a flour or starch. Banana flour had the highest final viscosity while mung bean flour had the lowest. Similar to breakdown viscosity, a significant negative correlation was found between final viscosity and crude protein content ($r=-0.626, p<0.01$). Among the flours, those that had amylose contents greater than 20% also had high setback values ($r=+0.692, p<0.01$). Non-glutinous rice, banana, sweet potato, and wheat flours had high setback values. Thus, it can be said that these three non-wheat flours have the highest retrogradation tendency. In line with this, bread produced from these flours could easily become stale.

A consistent trend in the relationship of different viscosity parameters between crude protein, crude fiber, and starch content was observed in this study. Generally, flours with higher starch content had higher viscosities (peak, trough, breakdown, and final) while those with higher crude protein and higher crude fiber content had lower viscosities.

**Gel Formation Ability.** A visual observation of the gels obtained from the different flours was done after the hydrothermal treatment at 95°C for 30 min (Figure 3).
Wheat flour produced a white, opaque, slightly firm gel. Non-glutinous rice flour also had a white and opaque gel but looked more paste-like. Glutinous rice flour produced a very sticky, white, opaque gel. Unlike the other flours, sweet potato flour had a translucent, hard, elastic gel that was difficult to pierce. Mung bean, banana, and sago flours all had gels that were brown, opaque, and firm. After storage at freezing temperature (−2°C), all the gels became firmer and assumed the shape of the container (centrifuge tube) except for glutinous rice flour, which retained a non-uniform and sticky gel.

Determining the gel-forming ability of the flour samples is useful in deciding whether they are good thickening agents. Flours and starches with good gelling properties are useful in baking since gel network structures serve to increase batter viscosity and strengthen the air cells in the bread’s crumb (Anton & Artfield 2008).

**Bread Characteristics**

**Specific Volume, Density, and Firmness.** Good quality breads have larger volume due to a more open crumb cell structure (San Francisco Baking Institute 2004). Conversely, inferior breads have firm, crumbling, and dry crumb structure and are not preferred by consumers (Rakkar 2007). Table 4 summarizes the different physical characteristics of the bread made from wheat and glutinous-free flours. The wheat bread had the highest specific volume (2.37 mL/g) and the lowest density (0.42 g/mL). In contrast, the bread samples with 50% gluten-free flours had significantly lower specific volume and were denser, which can be attributed to the reduction of gluten in the formulation. All these treatments, except for the one with sweet potato flour, had similar specific volume and density. The interaction of gliadins and glutenins in wheat flour forms a gluten network, which results in the formation of a viscoelastic dough that retains carbon dioxide during proofing and baking (Mariotti et al. 2009). This produces a light baked product. Conversely, the absence of gluten will lead to a highly dense (low volume) bread that does not resemble wheat bread (Rakkar 2007).

Bread density had a strong positive correlation with flour breakdown viscosity ($r = 0.620, p < 0.01$; Table 5), which is in agreement with the report of Zaidul and colleagues (2007) in their study on cassava, potato, sweet potato, and yam starch. On the other hand, bread density showed a strong significant negative correlation with water absorption capacity ($r = -0.523, p < 0.01$) and amount of flour retained in Mesh 200 ($r = -0.720$). This means that the desirable less dense bread may be produced from flours with low breakdown viscosity, small particle size, and high WAC.

All the bread samples from flour blends had a significantly greater compression value than the bread made from wheat flour. Among these samples, the one made from mung bean flour was the firmest, requiring 45.63 N to complete 40% compression. As mentioned, absence of gluten results in bread with low volume. Low volume bread has denser crust and compact cells; hence, gluten-free bread is firmer than wheat bread (De La Hera et al. 2014). Bread firmness can also be attributed to fiber and amylose contents; it was positively correlated with both fiber ($r = 0.465, p < 0.01$, Table 5) and amylose content ($r = 0.253, p < 0.01$). Fiber weakens the structure of the bread by interacting with gluten and disrupting the gluten network, thus reducing the dough elasticity and gas retention capacity (Gómez et al. 2003). On the other hand, amylose-rich starch in gluten-free bread tend to retrograde faster than wheat starch; thus, higher amylose content leads to a firmer bread (Rakkar 2007).

Generally, bread firmness and density correlated with flour composition and functional properties. To improve bread quality, substances such as hydrocolloids can be added to increase consistency of dough, reduce pasting temperatures, and decrease effects of staling and crumb firmness (Moreira et al. 2011).

**Table 4.** Quality characteristics of the bread samples made from different flours.

<table>
<thead>
<tr>
<th>Flour</th>
<th>Specific volume (mL/g)</th>
<th>Density (g/mL)</th>
<th>Firmness (N)</th>
<th>Crust color</th>
<th>Crumb color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L*</td>
<td>a*</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.37 c</td>
<td>0.42 a</td>
<td>10.00 a</td>
<td>64.51 b</td>
<td>13.47 d</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>1.63 b</td>
<td>0.62 b</td>
<td>36.10 c</td>
<td>84.13 d</td>
<td>3.21 b</td>
</tr>
<tr>
<td>Non-glutinous</td>
<td>1.32 a</td>
<td>0.76 bc</td>
<td>39.97 cd</td>
<td>82.50 d</td>
<td>3.75 b</td>
</tr>
<tr>
<td>Glutinous</td>
<td>1.17 a</td>
<td>0.87 c</td>
<td>21.62 b</td>
<td>83.07 d</td>
<td>1.76 a</td>
</tr>
<tr>
<td>Mung bean</td>
<td>1.19 a</td>
<td>0.85 c</td>
<td>45.63 d</td>
<td>54.90 a</td>
<td>15.08 e</td>
</tr>
<tr>
<td>Banana</td>
<td>1.17 a</td>
<td>0.86 c</td>
<td>44.05 cd</td>
<td>73.76 e</td>
<td>5.84 c</td>
</tr>
<tr>
<td>Sago</td>
<td>1.37 ab</td>
<td>0.73 bc</td>
<td>36.58 cd</td>
<td>61.05 b</td>
<td>13.35 d</td>
</tr>
</tbody>
</table>

Means in columns with different superscripts are significantly different at $p < 0.05$. 

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**Bread Color.** One of the most important indicators of bread quality is color. Golden brown crust and creamy white crumb are desirable and commonly accepted by consumers (Phattanakulkaewmorie et al. 2011). The crust and crumb color measurements of the bread samples are shown in Table 4. The 100% wheat had a light brown crust (L* = 64.51) and creamy white crumb (L* = 77.80). Mung bean bread had the darkest crust color (L* = 54.90) while sweet potato, non-glutinous and glutinous rice bread had the lightest crust. Glutinous rice bread crust had the lowest a* value while sago and wheat bread samples had the highest. Similarly, glutinous rice bread crust had the lowest b* value while wheat, sago, and mung bean had the highest.

The bread with glutinous rice, sweet potato, and non-glutinous rice had a generally whiter crust. In contrast, the crust of mung bean bread was the darkest, most saturated and most pigmented, followed by wheat, sago, and banana bread samples. L* value for bread crust and protein had a negative relationship (r = -0.462, p < 0.01). Relatively high protein content and available reducing sugars, which react and result in Maillard browning, or an inherent pigmentation in flours are some factors that influence the color of the bread.

Table 4 also shows the crumb color measurements of the bread samples. Sago bread had the darkest crumb color and highest a* and b* values. On the other hand, the bread with non-glutinous rice had the lightest crumb color and lowest a* and b* values. Wheat and sweet potato bread had similar a* and b* values as the non-glutinous rice bread crumb.

**CONCLUSIONS**

Local, underutilized, gluten-free flours from rice, sweet potato, banana, mung bean, and sago were studied. The physicochemical characteristics of the flours varied and affected functional properties and end-product quality. Mung bean flour has the greatest potential to improve the nutritional profile of a food product with its high protein (22.57%) and fiber (2.19%) contents. All the flours, except mung bean flour, have high starch content (72.70% to 81.50%) making them excellent thickeners. However, they differ in hot and cold viscosities and stability to heat and shear.

The 50% substitution of wheat with gluten-free flours produced bread samples with firmer and denser crumb. Specifically, correlation analysis showed that denser...
breads were observed from flours with larger particle size, high breakdown viscosity, and low water absorption capacity; firmer breads resulted from flours with high fiber and amylose contents. More studies are needed to optimize these formulations to improve both the bread's physical and nutritional quality. Other applications of these gluten-free flours include crackers, pasta, cookies, and other products that do not highly rely on gas retention to attain their structure.

This study provides a database of some non-wheat flours that could be valuable to food product developers in their selection of ingredients. With this, they could take advantage of the unique functional properties of the flours, their abundance in the local scene as well as their nutritional benefits.

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